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## **Static Load Test of Arquin-Designed CMU Wall**

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## **Static Load Test of Arquin-Designed CMU Wall**

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### **Abstract**

The Arquin Corporation has developed a new method of constructing CMU (concrete masonry unit) walls. This new method uses polymer spacers connected to steel wires that serve as reinforcing as well as means of accurately placing the spacers so that the concrete block can be dry stacked. The hollows of the concrete block used in constructing the wall are then filled with grout. As part of a New Mexico Small Business Assistance Program (NMSBAP), Sandia National Laboratories conducted a series of tests that statically loaded wall segments to compare the Arquin method to a more traditional method of constructing CMU walls. A total of 12 tests were conducted, three with the Arquin method using a W5 reinforcing wire, three with the traditional method of construction using a number 3 rebar as reinforcing, three with the Arquin method using a W2 reinforcing wire, and three with the traditional construction method but without rebar. The results of the tests showed that the walls constructed with the Arquin method and with a W5 reinforcing wire withstood more load than any of the other three types of walls that were tested.

## **Acknowledgments**

The authors would like to thank the Small Business Assistance Program for supporting this collaboration between Sandia National Laboratories and the Arquin Corporation. The authors would also like to thank Carlos Lopez and Jeff Smith from Sandia National Laboratories for their reviews and helpful comments on this report. The work described in this report was funded through the New Mexico Small Business Assistance initiative at Sandia National Laboratories. Neither Sandia nor the U.S. Government acquired any rights in any Arquin Corporation intellectual property as a result of this work.

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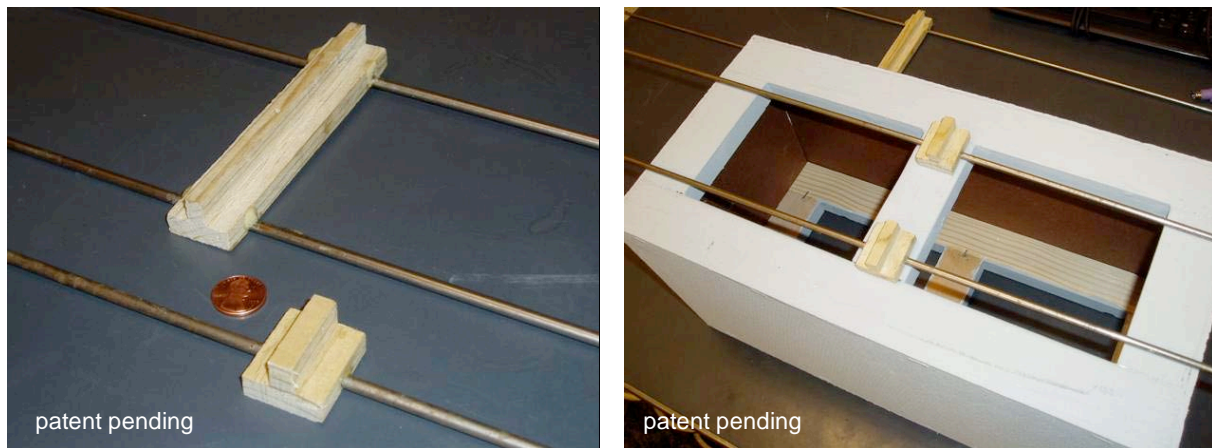
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## Introduction

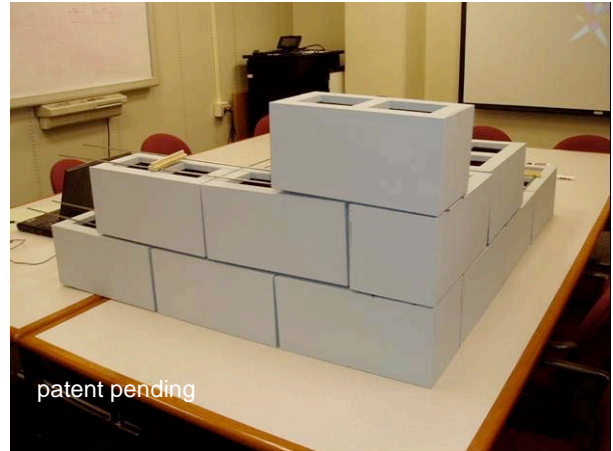
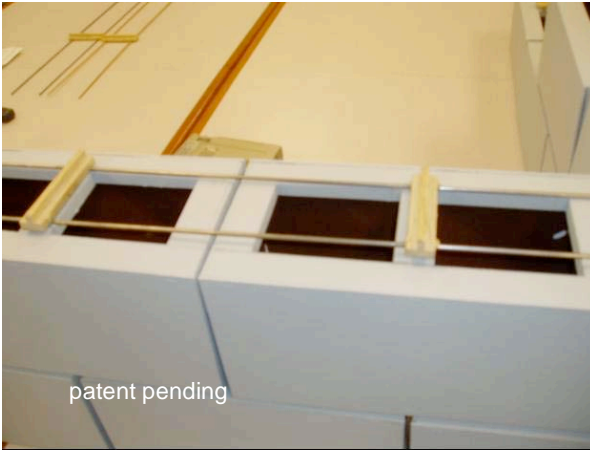
The Arquin Corporation has developed a new method of building concrete masonry unit (CMU) walls. This new method uses steel reinforcing wire and polymer spacers to rapidly dry stack the CMU blocks. The wire is configured into a continuous tie with the polymer spacers positioned so that the CMU block is located with the needed 3/8" vertical and horizontal spacing between each block. The spacers are placed on top of each course of block and the wire can be sized so that it acts as steel reinforcing for the wall. The original concept called for two wires per course of block as seen in Figure 1. The spacers allow for accurate and consistent block spacing. Figure 2 shows an assembly of blocks using the Arquin method. For this test, the original concept was modified to a single wire, located at the center of the block.

Through the New Mexico Small Business Assistance Program, Sandia National Laboratories (SNL) has provided technical assistance to the Arquin Corporation. Two separate analyses have been previously performed. The first was a study that used computational modeling to assess the construction method by evaluating suitable materials and designs to optimize the system and to assess the static load carrying capacity of walls constructed by the Arquin Method. These findings are detailed in the report written by Ho, et. al. (2008, SAND2008-5518). A second study by Lopez and Petti (2008, SAND2008-8123) reported a computational analysis of the Arquin method of wall construction under a dynamic loading condition.

This report details the results of a series of experiments that compares the performance of CMU walls constructed using the Arquin method versus the traditional method of constructing CMU walls. Throughout this report, when the term "Arquin wall" is used, it refers to the walls that were constructed using the Arquin method of construction. Whenever the term "traditional wall" is used, it refers to walls that were constructed using traditional construction methods.



**Figure 1.** Left: Prototype designs made of wood for the Arquin spacer. Right: Filaments (ties) comprising the spacers and 9-gage steel wires are laid on top of a CMU. (From Ho et al., 2008)



**Figure 2.** Left: Filaments of ties provide spacing and alignment for rows of CMUs.  
Right: Assembly of CMUs and filaments. (From Ho et al., 2008)

## Materials and Methods

Experiments were designed to statically apply a uniform load across one face of the CMU walls. The principal intent was to determine how well the CMU walls built using the Arquin method performed compared to the CMU walls built using traditional CMU wall construction methods. Table 1 is a test matrix of the experiment.

**Table 1.** Experiment test matrix

Arquin Method	Traditional Construction Method
W5 Wire Reinforcing	#3 Rebar Reinforcing
W2 Wire Reinforcing	No Reinforcing

Each wall was tested as a uniformly loaded, simply supported beam. The test procedure was to pick a wall up, rotate it 90°, set it on two supports, and then load it with a relatively uniform load. In order to apply the uniform load to each wall, a test frame/box was constructed. The test frame was lined with a plastic bladder. After the test frame was moved into place over the wall, the bladder was then slowly filled with water. The height of the water and the center point deflection of the simply-supported wall were recorded.

### **Wall Construction**

A total of twelve walls were built, three walls of each type described in Table 1. All of the walls were the same dimensions, nominally 9'-4" long, 2'-8" high, and 8" thick. The dimensions



correspond to seven full size (nominally, 16"x8"x8") CMUs long, four CMUs high, and one CMU thick. All CMUs used were off the shelf and complied with ASTM C90-06b.

The walls built with the traditional methods used a total of four courses of block. On the second and fourth courses, half blocks were used as the first and the last block of the course in order to enable the wall to be built with a running bond. A number three rebar was placed between the first and second courses and between the third and fourth courses. The rebar was placed down the center of the blocks. The blocks were bonded together with a Type N mortar. The mortar complied with ASTM C270-07a.

The Arquin method walls were built using five courses of block. The first and last courses were half-height block (nominally, 16"x8"x4"). These walls were also built with a running bond. One strand of reinforcing wire was placed down the center of the block between each course, since the block spacers were fixed to the reinforcing wire. The CMUs were dry stacked, using the spacers to align and locate each block. The spacers provided for a 3/8" vertical and horizontal gap between each block.

After the mortar used in the traditional construction method cured for two weeks, all of the block cores in each wall, traditional method and Arquin method, were filled with grout that complied with ASTM C476-07. The grout was specified as a 4000 psi, 3/8"- aggregate grout and had a slump of five inches. The last step in the Arquin method is to fill all of the spaces between the blocks with mortar. The walls were then allowed to cure for greater than 56 days. The reinforcing rebar used is a standard rebar compliant with ASTM A615, with a specified yield strength of 60 ksi. The reinforcing wire used is standard reinforcing wire compliant with ASTM A82/A82M with a measured yield strength of 79 ksi. The yield strength of the wire was measured at Sandia National Laboratories Structural Mechanics laboratory (Szklarz, 2008). Figure 3 shows the completed walls ready to be tested. An important point to note is that there was no vertical reinforcement install in any of the walls. This was done because the load on the wall would induce only flexural loading along the long axis of the wall. Since the vertical reinforcing would have been perpendicular to this load, it would not have contributed to the strength of the wall.



**Figure 3.** Test walls, constructed using traditional techniques, ready to be tested.



**Figure 4.** The image on the left shows the test frame as it is being placed over a CMU test wall. The image on the right shows the water depth gage and the deflection gage.

### **Testing Frame**

The testing frame was constructed with tubular steel and plywood. The interior dimensions of the box were nominally greater than 9'-4" x 2'-8". The height of the box was seven feet and was open on the top and on the bottom. The box was lined with a 12 mil plastic pond liner with sufficient material to allow the bladder, as it was being filled with water, to always remain in contact with the CMU wall as it deflected with no load being transferred back to the testing frame. This resulted in the CMU wall always supporting the vertical load of the water. A simple depth gauge was used to determine the height of the water that was being supported by the CMU wall. Figure 4 shows the testing frame and the depth gage.

The walls were supported at the ends by supports that were set apart at a distance of eight feet. The supports also supported the weight of the test frame. The supports were made from four foot long 4"x12" tubular steel with support plates and gussets (see Figure 4).

### **Data Recording**

The water depth and the wall deflections were captured through the use of HD Digital recorders. The cameras also captured the overall behavior of the walls as they deflected below the level of the test frame and as they failed. The data recording worked sufficiently well. Only two digital

recording cameras were used, one focused on the water level and the other on the deflection and the overall behavior of the wall.

### **Test Procedure**

The test procedure can be summarized as follows. First, a support bracket with a swivel hoist was bolted onto both ends of a wall. Rigging was attached to the swivel hoists and to a strongback attached to a fork-lift. The wall was then lifted and moved to where the test supports were located. The wall was rotated 90° and placed onto the supports. Next, the test frame was lifted into place and placed so that it fit over the walls and rested on the supports. At this point, the wall was completely inside the test frame without touching it (i.e., the test frame did not support the wall in any manner). Water was then pumped into the plastic bladder lining the test frame. As water was added, the water level and subsequent wall deflection were then recorded. The tests were run until the wall failed completely and fell to the ground.

Figure 5 is a photomontage of the sequence of steps involved in running the tests.



Rotating wall onto supports



Test wall resting on supports prior to testing.



Lifting test frame into place.



Filling test frame with water, during test.



Failed wall at end of test.



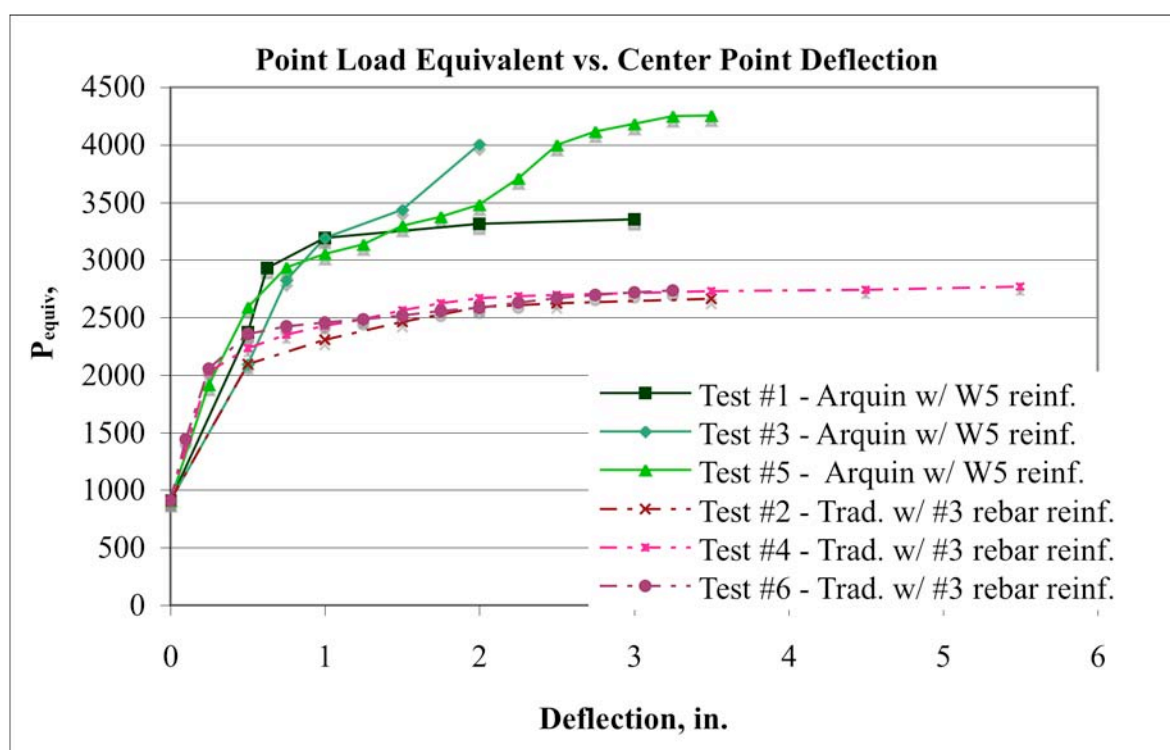
Failed Arquin wall.

**Figure 5.** Photo montage of test procedure.

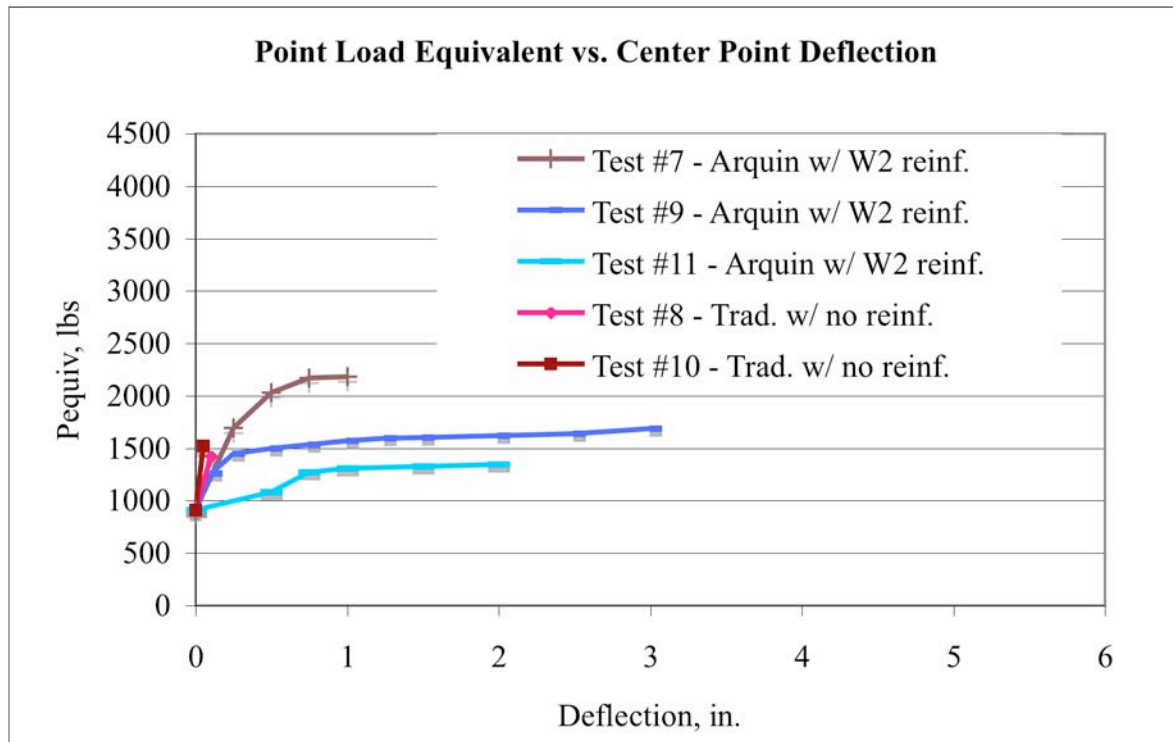


## Results

Figure 6 shows the load versus deflection curves for the Arquin walls with W5 reinforcing versus the walls built with traditional construction methods with a number 3 rebar reinforcing. Figure 7 shows the load versus deflection curves for the Arquin walls with W2 reinforcing versus the walls built with traditional construction methods without reinforcing. The load plotted in Figure 6 and Figure 7 is a point load that would induce a moment at the center point of the wall that is equivalent to the moment induced by the water load. How the equivalent point load is determined is discussed later in the report. Table 2 shows the wall deflection and the water depth at the time in which the walls failed catastrophically and fell to the ground.



**Figure 6.** Load versus displacement curves for the Arquin walls with W5 wire reinforcement and for the traditional walls with #3 rebar reinforcement.



**Figure 7.** Load versus displacement curves for the Arquin walls with W2 wire reinforcement and for the traditional walls without reinforcement.

**Table 2.** Deflection and water level at ultimate failure of wall.

Arquin Walls - W5 wire reinforcing			Traditional Construction - #3 Rebar reinforcing		
Test Number	Deflection, in.	H2O Level, in.	Test Number	Deflection, in.	H2O Level, in.
1	3	42	2	3.5	29.25
3	2	54.5	4	5.5	29.875
5	3.5	58	6	3.25	30.75

Arquin Walls - W2 wire reinforcing			Traditional Construction - No reinforcing		
Test Number	Deflection, in.	H2O Level, in.	Test Number	Deflection, in.	H2O Level, in.
7	1	22.25	8	0.1	9.25
9	3	12	10	0.05	11
11	2	6.5	12	Failed due to self weight	

It was observed that the Arquin walls all failed due to tensile failure of the wire reinforcing. In Test #1, all four strands of wire failed in tension, in Tests #3 and #9, three of the four reinforcing wires failed in tension and in Tests #5, #7, and #11, two of the four reinforcing wires failed in tension. The location of the wire failures was at the mid-point of the wall, which is the location of the maximum bending moment. The walls constructed in a traditional manner with reinforcing failed due to debonding of the reinforcing. None of the rebar failed in tension. All of the walls that had reinforcing exhibited ductile failure behavior. The non-reinforced walls exhibited the expected brittle failure. The last non-reinforced wall, Test #12, was unable to self-support its weight when placed on the test supports and failed prior to loading the wall with water.

### **Discussion of Results**

The principal objective of these tests was to determine if the Arquin method of constructing CMU walls performed as well as CMU walls that were constructed using more traditional construction methods. Turning the walls onto their sides and supporting them at the ends enabled the walls to be tested as a simply supported beam under an approximately uniform load, since the water level rises uniformly across the entire surface of the wall. In this configuration, the wall resists the load in flexure. Generally, when a reinforced masonry wall is loaded so that it flexes, the masonry is assumed to have no tensile strength and that the reinforcing steel carries the entire tensile load.

When the wall begins to flex and deflect downward, the actual load is no longer truly uniform, but greater in the middle (where the water is deeper). This makes it more difficult to compare the loads from one test to the next. In order to correct for this, the uniform load was converted to an equivalent point load at the center of the wall that would produce an equivalent maximum moment. It was assumed that the water load was a combination of two loads, a uniform load that was the measured height of the water and a load increasing uniformly to the center. By superimposing these two loads, a maximum moment,  $M_{\max}$ , at the center of the beam can be calculated using the following equation:

$$M_{\max} = \frac{(w_{H_2O} + w_{conc})l^2}{8} + \frac{Wl}{6} \quad (1)$$

where  $l$  is the distance between supports ( $l = 96''$  for all tests),  $w$  is the uniform load from the water or the self weight of the wall, and  $W$  is the load increasing uniformly to the center, approximated using a triangular area/volume. Furthermore,

$$w_{H_2O} = \gamma_{H_2O}hd \quad (2)$$

$$w_{conc} = \gamma_{conc}td \quad (3)$$

$$W = \frac{1}{2}\gamma_{H_2O}l\Delta d \quad (4)$$

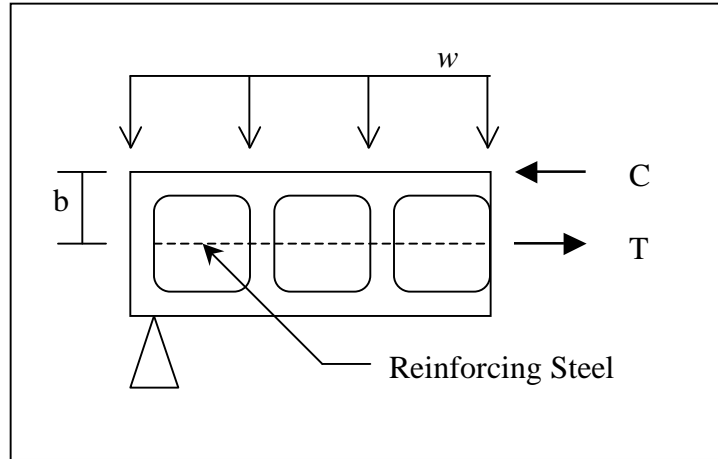
where  $\gamma_{H_2O}$  is the density of water,  $\gamma_{conc}$  is the density of concrete,  $d$  is the depth of the test frame ( $d = 32''$  for all tests),  $h$  is the height of the water,  $t$  is the thickness of the concrete block wall, and  $\Delta$  is the vertical deflection of the wall. The equation for computing the maximum moment of a point load on a beam is

$$M_{max} = \frac{Pl}{4} \quad (5)$$

where  $P$  is the concentrated point load located at the center of the beam. An equivalent point load ( $P_{equiv}$ ) is found by setting equation (1) equal to equation (5) and solving for  $P$ . This gives the following equation.

$$P_{equiv} = ld \left[ \gamma_{H_2O} \left( \frac{h}{2} + \frac{\Delta}{3} \right) + \frac{\gamma_{conc} t}{2} \right] \quad (6)$$

Using  $P_{equiv}$  makes it easier to compare test results.



**Figure 8.** Load diagram of a wall.

A simplified approach was also taken for predicting at what point the walls would yield. The approach taken was to assume that the wall acts as a simple beam resisting the load in flexure. Figure 8 shows a cut away of the wall acting as a beam with the tensile load being taken entirely by the steel reinforcing and the compressive load resisted by the concrete block. During the experiment, it was noted that the self-weight would cause cracks to form from the bottom of the wall/beam, along the web, to the face shell on the top. This left approximately one-inch of shell thickness to resist the compression. The moment carrying capacity of the beam can be computed by the following equation:



$$M_Y = T_Y b \quad (7)$$

where  $M_Y$  is the moment at yield,  $T_Y$  is the tension load capacity at yield of the reinforcing, and  $b$  is the distance from the center of the reinforcing to the center of the compressive region.  $T_Y$  is computed by:

$$T_Y = A_s F_Y \quad (8)$$

where  $A_s$  is the total area of reinforcing steel in the wall and  $F_Y$  is the yield strength of the reinforcing steel. For the #3 rebar,  $F_Y$  is assumed to be 60 ksi. For the reinforcing wire,  $F_Y$  was measured and found to be 79.2 ksi. A predicted  $P_{equiv}$  can be found by setting equation (7) equal to equation (5) and solving for  $P$ .

$$P_{equiv(predicted)} = \frac{4 A_s F_Y b}{l} \quad (9)$$

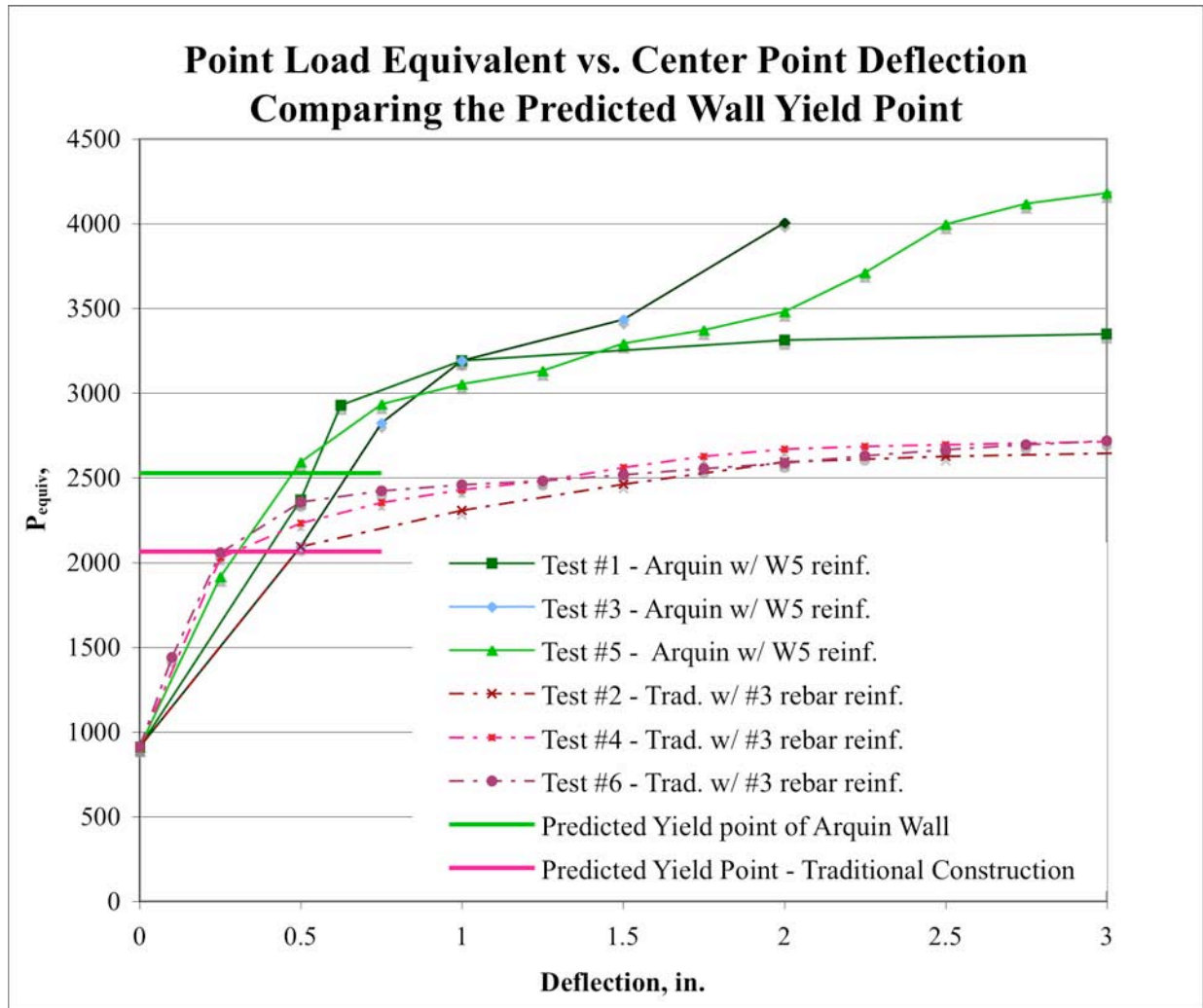
The predicted  $P_{equiv}$  at the yield point of the reinforcing steel for the Arquin walls and for the traditional wall is listed in Table 3.

**Table 3.** Magnitude of point load necessary to induce yield in the reinforcing steel.

Wall Type	Equivalent Point Load needed to induce yield in the reinforcing steel, lbs
Traditional - #3 Rebar	2063
Arquin - W5 Wire	2528
Arquin - W2 Wire	1103

Determining the yield point of the wall is neither a straightforward nor an easily determined point. The yield point is usually defined as the point at which a material transitions from the elastic (or recoverable) deformation regime to the plastic (or irrecoverable) deformation regime. Figure 9 shows the predicted point load equivalent that would induce yield in the reinforcing steel superimposed on the graph of the equivalent point load from the water load. The area of reinforcing steel in the Arquin walls is less than the area of steel in the traditional walls. However, the yield strength of the wire is about 24% greater than the rebar. The combination of lesser area and higher strength of steel predicts that the Arquin walls should be about 20% stronger as can be seen in Table 3. This is also illustrated in Figure 9. In this figure, one can see that the yield points of the traditional walls are very close to the predicted values. The yield points of the Arquin walls seem to be greater than the yield point that was predicted.

It is very difficult to draw any conclusions from the tests on the Arquin walls with the W2 wire reinforcing. It is unclear why a wide variability of the failure points was observed with these three walls, especially in light of the fact that Test #11 failed with less load applied than two traditional walls without any reinforcing, as illustrated in Table 2.



**Figure 9.** Load versus displacement curve for the Arquin walls with W5 reinforcing and reinforced traditional walls. The comparison is made to the load  $P_{equiv}$  necessary to induce the reinforcing in either wall type to yield.

## Summary

A total of twelve walls were tested under nearly static loading. Three walls were Arquin walls with W5 wire reinforcing, three walls were Arquin walls with W2 wire reinforcing, three walls were traditional walls with number 3 rebar, and three walls were traditional walls with no

reinforcing. The walls were tested as simply-supported beams with a uniform load applied to one of the surfaces of the wall and loaded until ultimate failure occurred.

The results of these tests show that a wall built using the Arquin method of constructing CMU walls, with reinforcing wires on every course, the block laid in a running pattern, all of the cores filled with grout, the spaces between the block filled with mortar, and all of the materials that were used complying with their respective ASTM specifications performs as well as a wall that was constructed using traditional construction methods for building CMU walls and that used the same materials with the exception of standard rebar instead of wire reinforcing. The differences in strength seen are mainly attributed to the differences in the strength of the reinforcing material used.

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